Original Report

Risk of giardiasis in Aucklanders: a case–control study

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Background: *Giardia* is one of the leading protozoal causes of human gastrointestinal illnesses. It is prevalent in both developed and developing countries. Currently, giardiasis is the most commonly notified waterborne disease in New Zealand. The aim of the study was to identify potentially modifiable risk factors for *Giardia* infection in the adult population in Auckland.

Methods: This case–control study involved 183 *Giardia*-positive cases and 336 randomly selected controls, aged between 15 and 64 years. Exposure information was collected retrospectively over the telephone for the 21 days preceding the date of onset of symptoms. Both univariate and multiple logistic regression analyses were carried out.

Results: The majority of cases were in the 25–44-year age group and in the New Zealand European ethnic group. Housewives and nursing mothers were at significant risk of the disease (odds ratio (OR)=2.06; 95% CI=1.4–3.74), as were the occupational groups exposed to human wastes (OR=4.04, 95% CI=1.85–8.85). Consumption of drinking water from New Zealand supplies other than metropolitan mains supplies (OR=2.11, 95% CI=1.36–3.27) or from sources outside New Zealand (OR=7.97, 95% CI=4.20–15.12) represented a significantly higher risk, as did traveling (OR=7.57, 95% CI=4.03–14.23) and swimming in pools or fresh water at least once a week (OR=2.04, 95% CI= 1.33–3.12).

Conclusions: The study identified potentially modifiable risk factors for *Giardia* infection. These findings should be investigated further in different groups and settings to ensure better protection of the public health.

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BACKGROUND

The parasite *Giardia* is now one of the leading causes of human protozoan gastrointestinal illness in the world. About 200 million people are infected with the parasite globally,[1] with 500 000 new cases reported annually.[2] Giardiasis occurs throughout tropical and temperate regions. The prevalence of the disease varies from 2–5% to 20–30% in developed and developing countries respectively.[3]

Giardiasis manifests as diarrhea associated with abdominal cramps, bloating, gas, fever, nausea, vomiting and anorexia. Transmission occurs mainly through the fecal–oral route. Contaminated water plays a role in spreading the agent. Epidemics have been mainly associated with improper handling of food, childcare center attendance and consumption of contaminated water. Travel to *Giardia*-endemic and -epidemic countries is also a risk. Giardiasis has been linked with certain occupations and behaviors,[4] and with lower socio-economic status and poor environmental conditions.[5]

Giardiasis is currently the third most common 'notifiable disease' in New Zealand and the most commonly notified waterborne disease. Nearly 2000 giardiasis cases are notified annually, an incidence rate of 49.4 per 100 000 population.[6] *Giardia* incidence by age in New Zealand shows a bimodal pattern of infection, peaking in the 1–4-year and 25–44-year age groups.[7]

There is limited evidence available on determinants of the disease which can be targeted in prevention activities. The study was undertaken to identify potentially modifiable risk factors for *Giardia* infection among the adult population in Auckland.

METHODS

Case–control methodology was used. A case was a resident of the Auckland (telephone) region aged

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between 15 and 64 years who had had *Giardia* isolated by one of the two pathologic laboratories in Auckland from a feces specimen and who could be contacted at home on a telephone number listed in the Auckland Telephone Book (ATB). Data were collected from cases diagnosed between July 1998 and June 1999. The pathologic laboratories informed general practitioners (GPs) about cases, with a request for patients to participate in the study. The research team obtained informed consent from cases referred by GPs before organizing an interview, which was conducted within 72 h of referral. When there was more than one case in a household, only the most recent case was included in the study. Controls, from the same age range as cases, were selected randomly from the ATB. The controls were not tested for *Giardia* but did not have a recent history of confirmed *Giardia* infection.

Interviews were conducted by telephone, which 96% of households in New Zealand have access to,[8] using a structured questionnaire investigating risk factors for giardiasis. Telephone Marketing Research (TMR) conducted the interviews for cases and controls, using the same questionnaire, following training by the researcher. Information on exposures was gathered for the 3 weeks preceding the date of onset of symptoms, which corresponds to the usual maximum incubation period for *Giardia* infection. To maintain a similar study period for controls, a single-digit random number ranging between 3 and 8 was generated for each control; this number was a proxy for days usually taken between the development of symptoms and pathologic diagnosis. So, for controls, information on exposures was gathered for the 3 weeks preceding an estimated date (simulated date of 'onset' had they been a case=(date of referral) − (a randomly assigned number of days between 3 and 8 to simulate time to diagnosis and referral in cases)).

Interviewers were blinded by allocating a computer-generated four-digit random number as the unique identification number of the cases and controls. Cases whose telephone numbers were not subsequently found in the telephone book were excluded from the study (n=11). The interviews were conducted in English, the national language.

Participants were categorized into six social classes based on occupation, using the New Zealand Socio-economic Index (NZSEI),[9] and those not employed were categorized according to either the nature of the unpaid work with which they were involved (self-employed, housewife/mothers at home, students) or their status as unemployed or retired.

The SAS (version 8.2, SAS Institute, Cary, North Carolina) statistical computer program was employed for data analysis. Initial univariate analysis used Mantel– Haenszel techniques to estimate the association between the disease and the specific potential risk factors. Multiple logistic analyses were then undertaken, for each set of risk factors and finally various combinations of significant risk factors of those sets in a series of models, to determine the individual effect of each significant risk factor, controlling for other risk factors and confounders. The reported odds ratio with 95% confidence intervals (OR (95% CI)) have been adjusted for age and gender for both univariate and multiple logistic analyses and tabulated for total study participants. The variable categories in a particular exposure group were mutually exclusive. The population attributable risk (PAR) of disease occurring was calculated using the proportion of exposure in controls.[10]

RESULTS

Two hundred cases were referred by GPs, resulting in 183 interviews, and 336 randomly selected controls were interviewed. The participation rate was calculated to be 91% of all cases referred to the study by GPs and 40% of laboratory-confirmed cases. Fifty-seven per cent of cases (n=105) and 55% of controls (n=184) were female. The mean ages for cases and controls were 39 (SD±10) and 40 (SD±12) years respectively. The age of participants was stratified into 10–year bands. Sixty-six per cent of cases were in the 25–44-year group. Seven per cent of cases were asymptomatic. Conversely, a similar proportion of controls was symptomatic. Analyses were repeated without them, and the result remained unchanged.

Study participants were allocated to five broad ethnic groups.[11] The largest group of study participants was of European origin (88.82%), similar to the national population pattern. Other ethnic groups included were Maori (6.17%), Pacific people (1.54%), Asian (3.28%) and African (0.19%). The ethnic distribution was the same for cases and controls.

Water used for drinking purposes during the 3 weeks preceding the actual or simulated onset date was categorized by source of supply (mains, bore, roof-collected rainwater or surface water), frequency (domestic or casual exposure), and location (overseas or local). No respondent used more than one source of drinking water at home. More than 80% used water from the Auckland Metropolitan Mains (AMM) supply for domestic purposes, and a further 15% of cases used roof-collected rainwater for the same purpose. In Auckland, use of the mains supply only was found to be associated with the lowest risk of *Giardia* infection (Table 1). The alternative New Zealand water sources (bore, river, roof-collected rainwater), whether used domestically or casually away from home, were associated with a significantly increased risk of infection (OR=2.41). However, the association was statistically significant only for roof-collected rainwater (OR=2.31), which was confirmed by multiple logistic analysis (OR=1.60). The risk was also higher for the consumption of drinking water from other main sources of urban supply than the AMM supply (OR=1.53), but this was not significant. An eight-fold increased risk of infection was found in multiple logistic analysis for individuals

who consumed water outside New Zealand (OR=7.97) compared to those who consumed AMM water only. The combined multiple logistic model also showed significantly increased risk of infection for consumption of non-mains water controlling for other risk factors (Table 2, model A).

Water sports (Table 3) were found to be significantly associated with infection (OR=1.57). Swimming was the most popular water sport and was significantly related to infection, especially for those who swam in pools (OR=1.78) or surface waters (OR=6.35) or at least once a week (OR=1.95). In multiple logistic regression analysis, the relationship was sustained (OR=2.04) for frequent swimmers (weekly), compared with the risk for those swimming less than weekly, but disappeared when drinking water sources (Table 2, model A) and/or overseas travel (Table 2, model C) were included in the model.

The risk of infection was significantly higher for housewives and nursing mothers compared to other social classes in both univariate (OR=1.79, 95% CI=1.04–3.09, P<0.05) and multiple logistic analyses (OR=2.06, 95% CI=1.14–3.74). Exposure to human wastes significantly increased (OR=4.35) the risk of infection. Significant associations were observed for exposure to nappy changing (OR=4.96) and for occupational exposure to human wastes (OR=2.85). For non-occupational exposure, the risk was high (OR= 2.11) but not significant (Table 4). However, in multivariate analysis, any type of exposure to human waste was significantly associated with infection (Table 2 and Table 4, models A–C) other than for non-occupational exposure when asymptomatic cases and symptomatic controls were excluded from the combined models (OR=2.73, 95% CI=0.89–8.39 (model A with exclusions applied)).

Those handling pets showed no increased risk of *Giardia* infection. Contact with farm animals in general was associated with an increased risk of infection (OR=1.74, 95% CI=1.07–2.82, P<0.05), although this was not linked to any one type of farm animal.

Traveling was divided into two broad categories, 'domestic' (OR=1.57) and 'international' (OR=7.00). Both were significantly associated with *Giardia* infection in multiple logistic analysis (Table 5). Strong associa-

Table 1. Risk of giardiasis by exposure to drinking water

Use of Drinking Water by Supply Source[a]	*Case n=183*	*Control n=336*	*Adjusted OR (95% CI)*[c]	*Logistic OR (95% CI)*[c]
Auckland metropolitan mains (AMM) only[b]	43	159	1.00	1.00
Other water sources except AMM	122	150	3.13 (1.94–5.05)	–
Water drunk outside NZ	42	17	13.82 (5.05–37.84)	7.97 (4.20–15.12)[d]
Other mains in NZ except AMM	18	40	1.53 (0.67–3.52)	1.37 (0.73–2.58)[d]
Other sources in NZ (home/away)	62	93	2.41 (1.38–4.22)	2.11 (1.36–3.27)[d]
Rain/roof-collected water	53	80	2.31 (1.27–4.20)	1.60 (1.07–2.40)[e]
Bore water	5	8	3.70 (0.82–16.70)	1.16 (0.38–3.56)[e]
River water	4	5	3.07 (0.59–15.99)	2.78 (0.82–9.39)[e]

[a]Missing values: case=18, control=27; [b]Reference group. [c]Age and gender adjusted.
[d]Variables in same logistic regression. [e]Variables in same logistic regression. NZ, New Zealand.

Table 2. Combined multiple logistic regression models for potential risk factors of *Giardia* infection during the 3-weeks study period

Regression Models	*Logistic OR (95% CI)*[b]		
	A	*B*	*C*
Drank Auckland Metropolitan Mains (AMM) only[a]	1.00		
Drank water outside New Zealand (NZ)	8.78 (3.82–20.16)		
Drank from other than mains in NZ	2.10 (1.26–3.49)		
Drank mains other than AMM in NZ	1.21 (0.58–2.53)		
No water sport exposure[a]	1.00	1.00	1.00
Swam weekly or more frequently	1.42 (0.85–2.36)	1.67 (1.03–2.71)	1.50 (0.91–2.48)
Swam less frequently than weekly	0.91 (0.49–1.68)	0.99 (0.55–1.79)	0.95 (0.51–1.76)
No exposure to human wastes[a]	1.00	1.00	1.00
Exposure to child's nappy	7.03 (4.31–11.48)	6.13 (3.83–9.81)	6.81 (4.19–11.07)
Occupational contact with human wastes	5.26 (2.27–12.20)	4.58 (2.04–10.30)	4.88 (2.12–11.21)
Non-occupational contact with human wastes	3.33 (1.14–9.74)	3.06 (1.09–8.55)	3.36 (1.15–9.78)
Did not travel[a]	1.00	1.00	1.00
Stayed in holiday chalet or rental housing	1.62 (0.69–3.81)	2.76 (1.26–6.05)	2.05 (0.89–4.70)
Stayed in hotel or motel during travel	1.25 (0.59–2.66)	3.05 (1.67–5.60)	1.20 (0.57–2.53)
Other accommodations: camp/boat/beach/private home	0.73 (0.39–1.34)	0.96 (0.54–1.71)	0.85 (0.47–1.54)
Asia and Africa			8.99 (3.12–25.93)
South Pacific countries (including Australia)			6.87 (2.33–20.24)
Europe			1.62 (0.27–9.86)

[a]Reference group. [b]Age and gender adjusted.

Table 3. Risk of giardiasis by exposure to recreational water

Exposure to Recreational Water	*Case n=183*	*Control n=336*	*Adjusted OR (95% CI)[b]*	*Logistic OR (95% CI)[b]*
Exposure No[a]	88	199	1.00	1.00
Exposure Yes	95	137	1.57 (1.05–2.35)	–
Swimming	86	113	1.74 (1.14–2.66)	–
Weekly or more frequently	59	66	1.95 (1.22–3.13)	2.04 (1.33–3.12)[d]
Less frequently than weekly	27	47	1.42 (0.74–2.72)	1.29 (0.76–2.20)[d]
Swimming/spa pool	55	67	1.78 (1.08–2.94)	1.85 (1.20–2.86)[e]
River/stream/lake	7	2	6.35 (1.38–29.24)[c]	7.74 (1.57–38.15)[e]
Sea	24	44	1.33 (0.68–2.58)	1.26 (0.73–2.20)[e]

[a]Reference group. [b]Age and gender adjusted. [c]Logit estimation.
[d]Variables in same logistic regression. [e]Variables in same logistic regression.

Table 4. Risk of giardiasis by exposure to human wastes

Contact with Human Wastes	*Case n=183*	*Control n=336*	*Adjusted OR (95% CI)[b]*	*Logistic OR (95% CI)[b]*
Exposure No[a]	63	241	1.00	1.00
Exposure Yes	120	95	4.35 (2.71–6.98)	–
Nappy changing	97	72	4.96 (2.89–8.51)	5.68 (3.65–8.85)[c]
Occupational exposure	15	14	2.85 (1.07–7.60)	4.04 (1.85–8.85)[c]
Non-Occupational exposure	8	9	2.11 (0.70–6.36)	3.45 (1.27–9.36)[c]

[a]Reference group. [b]Age and gender adjusted.
[c]Variables in same logistic regression.

Table 5. Risk of giardiasis by travel destination and accommodation

Travel	*Case n=183*	*Control n=336*	*Adjusted OR (95% CI)[c]*	*Logistic OR (95% CI)[c]*
Travel No[a]	82	225	1.00	1.00
Travel Yes	101	111	2.40 (1.59–3.63)	–
Domestic travel	59	94	1.57 (0.98–2.51)	2.17 (1.31–3.62)[e]
International travel	42	17	7.00 (3.33–14.73)	7.57 (4.03–14.23)[e]
Asia and Africa	20	7	11.10 (3.25–37.88)	6.77 (2.78–16.50)[f]
South Pacific (including Australia)	20	6	12.24 (3.02–49.51)	7.73 (3.03–19.73)[f]
South Pacific	10	0	5.94 (1.49–23.68)[d]	–
Australia	10	6	6.84 (1.55–30.29)	3.85 (1.37–10.85)[f]
Europe	2	4	0.90 (0.16–5.21)	1.15 (0.21–6.40)[f]
Accommodation used[b]	84	96	2.19 (1.42–3.39)	–
Holiday chalet/house-rented	22	14	4.95 (1.83–13.36)	3.95 (1.93–8.07)[g]
Hotel/motel	32	32	2.81 (1.47–5.40)	2.52 (1.46–4.36)[g]
Camping/boat/bach/private home	30	50	1.26 (0.69–2.31)	1.42 (0.85–2.36)[g]

[a]Reference group; [b]Missing values: case=17, control=15. [c]Age and gender adjusted; [d]Logit estimation.
[e]Variables in same logistic regression; [f]Variables in same logistic regression; [g]Variables in same logistic regression.

tions were observed with travel to Africa, Asia, South Pacific countries, and Australia (Table 5). The associations were sustained when sources of drinking water were not included in a multiple logistic regression model (Table 2, model C). Accommodation used during travel also showed a significant association in multiple logistic analysis, particularly for holiday chalets/houses–rented (OR=3.95). In combined models for multiple logistic analyses, types of accommodation were not significant when either drinking water sources or traveling outside New Zealand were included (Table 2, models A and C).

DISCUSSION

The aim of the study was to identify potentially modifiable risk factors among *Giardia*-infected Aucklanders aged 15–64 years. Telephone interview was used as the procedure for data collection.[12] The same questionnaire and interview procedure was used for cases and controls, to minimize observer and information bias. Underreporting is a problem in *Giardia* disease surveillance.[13] A high proportion of *Giardia* cases remain asymptomatic.[14] Only one-fourth of those infected experience symptoms, and asymptomatic carriers may be a signi-

ficant source of infection. This makes it difficult to assess the disease burden in the community. Our study included laboratory-diagnosed cases who were mostly symptomatic (93%). It is possible that some of the controls had asymptomatic *Giardia* infection. This misclassification error could be expected to decrease the exposure difference between cases and controls, although reanalyses by excluding asymptomatic cases and symptomatic controls did not change the results.

According to the 1996 census, the Auckland population between 15 and 64 comprised 63.4% European, 10.8% Maori, 10.1% Pacific people and 9.6% Asian, with the rest belonging to other ethnic groups. In this study, Europeans were over-represented at the expense of Maori, Pacific people and other ethnic groups.[15] The low proportions of Asians and other minority ethnic groups may be due to cultural barriers or differences in response to illness and/or less access to medical services. Other surveillance data have found symptomatic *Giardia* infection rates to be higher among males.[5] The larger female participation in the current study was statistically insignificant but was consistent with other New Zealand studies.[16] As with similar studies,[5,12] female cases of childbearing age (25–44 years) formed the largest group. *Giardia* surveillance data held at the Auckland District Health Board (ADHB) for the same period of time also showed a similar trend.[7] This finding supports person-to-person or household transmission as an important determinant of infection, as children are more frequently infected with *Giardia*[17] and are likely to transmit the disease to other household contacts.[18] A significant risk of infection for housewives and nursing mothers again supports person-to-person infection,[12] and is consistent with the association with nappy changing.[19] The association with some occupations raises concerns regarding a possible work-related risk of infection.[20] However, the risk for non-occupational exposure was not significant in a separate (combined) multiple logistic model when asymptomatic cases and symptomatic controls were excluded, possibly due to smaller sample size.

Water has been reported to be responsible for both endemic and epidemic giardiasis.[21,22] The organism has been reported to be abundant in New Zealand surface water.[23] The present study has found the AMM water supply to be protective, which is consistent with the results of the annual review of microbiological monitoring.[24] However, routine water monitoring does not always guarantee safety if the sampling site is not representative of the entire system or a fault affects a small part for a short period.[25] The risk of infection was higher among the users of non-mains water supplies in general and particularly among the users of roof-collected rainwater, supporting the outcome of a similar study conducted in other New Zealand cities.[26] Contamination of roof tanks with *Giardia* cysts of fecal origin is not unlikely,[27] although *Giardia* cysts were not identified in a study of roof-collected rainwater systems in the region.[28] Although bore water supplies (ground water supplies) and supplies drawn from river water showed an increased risk, this was not significant, probably due to small numbers. These largely private water systems supply a small group in the community and are susceptible to protozoan contamination,[29,30] as they may rely on chlorination or filtration, which are not always sufficient to remove *Giardia*,[25] or may not be treated at all. The risk to travelers is well known.[31] A greatly increased risk for those drinking water overseas compared to New Zealand water users could be due to non-mains water uses (Table 2, model A). This suggests a need for stronger messages for travelers intending to visit *Giardia* endemic areas.

One report has suggested that international travel is responsible for 10% of *Giardia* infections.[32] A seven-fold increased risk, found in the current study, for visiting endemic areas may be due to consumption of contaminated water.[31] The potentially high risk for visitors to South Pacific countries should not be underestimated, as these neighboring countries have close connections with New Zealand. The association between travel to Australia and giardiasis was potentially confounded by the Sydney water crisis in July 1998, which coincided with the study period, although no outbreaks of giardiasis were reported.[33] The study data recorded types of accommodation but did not separate domestic from international travel. The significant risk associated with staying in hotels or holiday chalets confirms the findings of another study.[34] Holiday chalets here refers to a kind of private accommodation similar to rental houses but reduced in size and facilities, often with shared cooking facilities and ablution blocks. However, in multiple logistic analyses, the risk for this type of accommodation was probably confounded by drinking water used and/or by exposure to other regions visited overseas. Camping is considered to be a potential risk factor,[34] though insignificant in the present study, due to insufficient numbers.

Recreational water exposure is causally associated with gastrointestinal diseases when contaminated water is consumed.[35] A significant potential risk associated with swimming in pools might be confounded by variability in the quality of pool water or seasonality. We had minimal data on the quality of water for pools either in or outside New Zealand. A dose–response relationship associated with the frequency of swimming is likely to be related to the quality of bathing water.[36] Small numbers weakened the implications of the study for exposure to river water. However, rivers and lakes are frequently contaminated, especially during rains, storms, floods, and when human activity increases during favorable weather conditions.[37] Reports suggested that the *Giardia* spp. infective to human are likely to survive for less time in seawater.[38,39] This supports our finding of an insignificant risk for those swimming in seawater. Nevertheless, this finding should be interpreted with caution, as the concentration and viability of parasites in seawater depend on water temperature, salinity and water quality.[38,39] The

impact of other water sports included in the study may have been masked due to a variable level of exposure to water.

Analysis of 4 years' notification data (July 1996 to June 2000) suggests that the rate of *Giardia* infection among children under 5 is five times higher than for all other age groups.[7] Chronic and repeatedly infected children are an important source of infection for others, and the infection rate rises precipitously once they attend a childcare facility.[40,41]

This study demonstrated that a high proportion of disease in the community is potentially modifiable if the risk factors identified can be addressed. The study identified risks from exposure to contaminated water and to human wastes. Some specific risk factors, such as frequent swimming (PAR%=20.3), drinking of non-mains water (PAR%=35.2), travel (PAR%=33.1), the use of contaminated water outside New Zealand (PAR%=44.9), occupational exposure to potentially contaminated human wastes (PAR%=15.7) or exposure to nappy changing (PAR%=48.8) had strong associations with giardiasis. These associations warrant further investigation. Concerns about recreational water quality and the risk of travel, which have long been challenges to health protection, are reinforced by this study. The high representation of women of childbearing age suggests a target group for effective health promotion. The association with exposure to feces suggests possible settings for preventive intervention (e.g. early childhood centers). The major risk factors were not mutually exclusive but rather complementary. The risk factors identified need to be prioritized for public health protection through future research and intervention involving different groups and settings.

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